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Were ancient seals secure?

Roger G. Johnston, Debbie D. Martinez, & Anthony R.E. Garcia*

Abstract
Forgeries of ancient seals have been found in modern times, but there has been little previous analysis of how much security ancient seals might have offered. In this paper, we demonstrate four different vulnerabilities of clay seal impressions using attack methods and materials that were available thousands of years ago. The success of these attacks suggests that ancient stamp and cylinder seals may have been highly vulnerable to spoofing.

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Introduction

Stamp and cylinder seals were widely used in the ancient world. They were made by inscribing symbols or a design into wood, bone, clay, or stone (Gibson and Briggs 1977; Colon 1987; Colon 1990). The seal pattern could then be impressed into wet clay. The clay containing the seal impression, sometimes in conjunction with twine or rope, was used to seal the object or container of interest such as a jar, basket, bundle, sack, door, or document. The clay was allowed to harden by drying or by baking in the sun. Any attempt to gain unauthorized access would require either damaging the container or cutting the twine/rope, which would be noticeable, or else destroying the seal impression, which would supposedly be difficult to reproduce without possessing the original seal. Other security applications for seals probably included identifying people, authenticating documents, demonstrating signature and legal authority, marking ownership and trademarks, and assisting with customs, taxation, and business contracts (Gibson and Briggs 1977; Colon 1987: 113-119; Colon 1990: 11-30). Non-security applications may have included personalization, labeling, time and location stamping, counting, ceremony, magic, and decoration (Gibson and Briggs 1977; Colon 1987: 113-119).

Stamp seals were first used at least 7000 years ago, becoming especially popular in Middle Eastern and Aegean civilizations of the 2nd and 3rd millenniums BC (Gibson and Briggs 1977; Collon 1987: 13-93). Cylinder seals were invented around 3500 BC and were in widespread use from 3000 to 500 BC (Collon 1987; Collon 1990: 11-20). Both types of seals were also found in the New World (Enciso 1953). Wax or resin eventually replaced clay as the preferred sealing material in the 1st millennium AD, with lead seals coming into use by the 4th century AD (Vikan and Nesbitt 1980: 23-28).

Given the importance of seals, the question of how secure they might have been is of interest. Forged ancient seals have been detected in modern times (Porada 1957; Porada 1978; Collon 1987: 94-96; Collon 1990: 56-57; Gorelick and Gwinnett 1978: 40-43 & figures 7A-D). There appears, however, to be little previous analysis of ancient seal security.

The Vulnerability Assessment Team at Los Alamos National Laboratory (LANL) has extensively studied *modern* seals (Johnston 1997; Johnston 2000). The goal is to determine how the seals can be defeated, and then to devise countermeasures. To "defeat" a seal means to remove it, then reseal (using either the original seal or a counterfeit) without being detected. To "attack" a seal means to try to defeat it.

This paper discusses a vulnerability assessment conducted on clay seal impressions similar to those made by ancient stamp and cylinder seals. As a result of this work, ancient seals do indeed appear to have been vulnerable to fairly simple attacks using materials available several thousand years ago.

The Attacks
We experimented with four possible attacks. None require access to the original seal, only to an impression made by the seal.

Beeswax casting attack
We use liquid (heated) beeswax to cast a copy of the stamp seal impression. Olive or sesame oil is lightly brushed on the original clay impression prior to casting to serve as a mold release. The beeswax solidifies within 3 minutes and can then be used to create multiple counterfeit seal impressions.

Clay casting attack
We use wet clay to make a copy of the stamp seal impression. Oil is again used as a mold release. Once the clay is removed and allowed to dry and harden, it can be used to make counterfeit seal impressions.

Counterfeit carving attack
We make a free-hand counterfeit carving (forgery) of the cylinder seal based on the seal impression. The counterfeit cylinder seal can be used multiple times to create fake seal impressions.

Cut and past (cookie-cutter) attack
We use water and a metal tool to cut the seal impression out of the clay. It is then patched and blended into wet clay, which is allowed to dry. Unlike attacks 1-3, which involve counterfeiting, this attack reuses the original seal impression.

Experimental Materials and Ancient Availability
We obtained modern brass stamp seals from Nostalgic Impressions (Selden, NY). See figure 1. They are intended for the decorative sealing of paper envelopes using wax. The three types of soft clay used in this work (5 to 5.6 penetrometer) were purchased from New Mexico Clay (Albuquerque, NM): Terra Cotta (TC), Red Earthenware (RL6), and white Storyteller (APSW). Reported shrinkages were 7%, 8.5%, and 8%, respectively.

The beeswax used for casting the seal impressions (#12-0050, melting point 62°-65° C) was obtained from J&N Sales (Kokomo, IN). Beeswax has been available for thousands of years. Aborigines in northern Australia, for example, were carving beeswax figures 30,000 to 50,000 years ago (Cherry 1993). Rock art suggests that hive products were collected in Europe by 6000 to 7000 BC, and possibly much earlier (Crane 1983: 19-27, 35). Beekeeping is known to have been well established in Egypt by 2400 BC (Crane 1983: 36). Lamps from the Late Minoan I period, c. 1600-1450 BC, may have burned beeswax based on chemical analysis (Evershed, et al. 1997). Beeswax is mentioned in the Linear B tablets (Chadwick 1973: 290, 302, 465). Homer (8th century BC or earlier) has Odysseus taking beeswax from a "great wheel" (so presumably it was not scarce) and putting it in his mens' ears to

prevent them from hearing the Sirens (Odyssey 12: 173-200). The remains of a 700 BC funerary feast (possibly for King Midas) show traces of both olive oil and beeswax (McGovern, et al. 1999). Even if beeswax were not available at a particular time and place, other waxes (Coggshall and Morse 1984: 13-15) could have been used. Tree sap or ice (in cold climates) might also work.

The olive and sesame oils used as mold releases were obtained from Furr's Supermarkets (Albuquerque, NM) and General Nutrition Corporation (Pittsburgh, PA), respectively. Without a mold release, the beeswax or clay casting tends to stick to the original seal impression and become damaged when it is removed. Olive and sesame oils were available to most civilizations that used seals. Sesame oil was well known in ancient Mesopotamia (Runnels and Hansen 1986; Waetzoldt 1985; Charles 1985). Olive oil was possibly used in Greece and Crete during the Early Bronze Age, and perhaps even in the Neolithic (Runnels and Hansen 1986). Olive oil is mentioned occasionally in Mesopotamian texts from the 3rd millennium BC (Malul 1996: 94). It was widely used in the second millennium BC throughout the Aegean (Runnels and Hansen 1986; Evershed, et al. 1997), and is discussed frequently in the Linear B tablets (Chadwick 1973: 128-131, 217, 476, 477; Runnels and Hansen 1986). A primitive olive oil press has been found in Ugarit from 2300 BC, with olive oil appearing in Ugaritic texts pre-dating the 13th century BC (Heltzer 1996: 79-89). Olive oil is mentioned in Egyptian documents from the 19th and 20th Dynasties (Ahituv 1996), 1292 to 1075 BC, and in the Pentateuch, 9th to 5th centuries BC, including Deuteronomy 8:8; Exodus 27:20, 29:4-9, 30:22-31, 40:12-15; and Leviticus 24:2, 14:12-24. A variety of other oils and fats were available to most ancient seal-using civilizations (Runnels and Hansen 1986; Waetzoldt 1985; Charles 1985) that could also serve as mold releases. Saliva and skin oil work, too, though not as effectively.

Testing the Counterfeits

For the beeswax and clay casting attacks, we tested the effectiveness of our counterfeit seal impressions with a double blind survey using volunteers who were LANL employees. The test subjects were asked to distinguish between original and counterfeit seal impressions.

For experiment 1, subjects were given a small rectangle of clay with an original seal impression. They were told this impression was an original and were asked to study it carefully. The original was then taken from them and they were not allowed to examine it again during the course of experiment 1. They were next immediately shown small clay rectangles (see figure 2), one at a time, and asked to determine if the impression on each was an original or a counterfeit. Subjects could take as long as they wanted, but they could only observe one impression at a time, could not re-examine the first original they were shown or an earlier impression once they had made a decision about it, nor change previous decisions. Subjects were not allowed to touch the clay rectangles except along the edges.

Experiment 2 was similar except that the test subjects were allowed to keep the first seal impression that was identified for them as an original. They compared this original seal impression side-by-side with each of the seal impressions one at a time. The same seal impressions were used as in experiment 1, but were presented in a different random order.

Experiment 3 involved multiple impressions placed on large clay tablets. Subjects were told that the impressions located at the top of each tablet were originals. They then examined all the impressions on each tablet and tried to identify the counterfeits.

Results & Discussion

Figures 3 through 5 show the original seal impressions prior to casting, alongside the counterfeit(s) made from them using beeswax or clay castings. The counterfeits are clearly good reproductions of the originals. Both our beeswax and clay counterfeit seals can be used for at least several hundred quality seal impressions, though the beeswax castings are more durable.

The survey results, summarized in tables 1-3, indicate that the test subjects had difficulty in distinguishing the counterfeits made with beeswax or clay castings. They were wrong nearly one-third of the time, on average. Seal inspectors not alerted to the definite presence of counterfeits, and not given unlimited inspection time, would presumably make even more errors. Many of the test subjects expressed frustration at the difficulty of the task, and at the lack of information about how to spot a counterfeit. This may have been realistic. We do not know what ancient seal inspectors were told to look for, but modern seal inspectors are typically not given much guidance (Johnston 1997; Johnston 2000).

In figure 6, we plot how frequently each individual mistakenly thought a counterfeit seal was authentic (type 2 error) vs. how frequently he/she mistakenly thought an original was fake (type 1 error). An indication of the difficulty in correctly identifying counterfeits can be obtained from fitting the data. Linear least squares fits were applied to the beeswax casting attacks and to the clay casting attacks. The intercepts of these two lines with the vertical and horizontal axes tells us that in the limit of 0% type 2 errors, the average type 1 error rate is 63% and 57% for the beeswax and clay casting attacks, respectively. In the limit of 0% type 1 errors, the average type 2 error rate is 49% and 29%, respectively. These are very high error rates.

Despite the instructions given to the test subjects that counterfeits were substantially in the minority, and that type 1 (false reject) errors were as serious as type 2 (false accept) errors, most subjects claimed that an inordinate number of seal impressions were counterfeit. This is not surprising. If modern seal inspectors are alerted that counterfeits are among the seals they will inspect (a somewhat artificial situation since adversaries do

not usually announce when they are attacking seals), the inspectors become paranoid and report large numbers of counterfeits, even when fully aware that falsely accusing a seal of being a counterfeit has serious repercussions.

The most reliable way to detect the counterfeits is to note that they are slightly undersized. For the beeswax casting attack, the counterfeit impressions were 0% to 12% shorter in each dimension than the original seal impressions. The mean was 7.5%. This is less shrinkage than might be expected, given the shrinkage of the clays as they dry, plus the fact that unconstrained beeswax shrinks 9.6% as it solidifies (Coggshall and Morse 1984: 17). The shrinkage for the counterfeit impressions made with clay castings was 4% to 14%, with a mean of 9.5%.

Figure 7 shows the results of the counterfeit carving attack. The top half of the figure is an impression from an ancient cylinder seal; the bottom half shows an impression from a counterfeit seal carved into a cylindrical piece of wood by one of us, Garcia. Garcia is an amateur wood carver with no previous experience carving cylinder seals. This counterfeit seal was carved free-hand by visual reference to the upper seal impression in figure 7. We believe a second attempt would produce a better counterfeit, as would a carver with greater experience or skill.

A seal inspector who compared the counterfeit seal impression in figure 7 with an original would probably not be fooled. If, however, the inspector failed to compare the seal impression alongside one known to be authentic, he/she might get fooled because the counterfeit reproduces the rough overall pattern. Inspectors are particularly likely to be fooled if the quality of the original seal impression or clay was poor, if the inspector devoted little care to the inspection, and/or if the inspector was not thoroughly familiar with the seal design. Modern seal inspectors rarely compare seals side-by-side, though we believe this improves tamper detection (Johnston 1997).

Figure 8 shows an example of a cut and paste attack. The original seal impression was undamaged.

We do not know if ancient seal users were generally aware of the vulnerabilities demonstrated in this work. Perhaps not. Modern seal users often know little about the vulnerabilities of the seals they use (Johnston 1997; Johnston 2000). On the other hand, given the extensive use of seals in many civilizations, perhaps ancient seal users were fully cognizant of the problems. A certain amount of seal fraud may have been accepted as inevitable--much the way that modern societies accept occasional credit card fraud as simply part of the cost of doing business.

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Tables

Table 1 - Survey parameters.

attack	no. of people	experiment 1: no. of counterfeits, originals	experiment 2: no. of counterfeits, originals	experiment 3: no. of counterfeits, originals
beeswax casting	29	11, 37	11, 37	6, 16
clay casting	17	8, 24	8, 24	8, 15

Table 2 - Average survey results for the **beeswax casting attack**.

	experiment 1	experiment 2	experiment 3
counterfeits not detected (type 2 errors)	19%	18%	32%
originals incorrectly thought to be counterfeits (type 1 errors)	50%	54%	26%

Table 3 - Average survey results for the **clay casting attack**.

	experiment 1	experiment 2	experiment 3
counterfeits not detected (type 2 errors)	13%	6%	47%
originals incorrectly thought to be counterfeits (type 1 errors)	57%	59%	29%

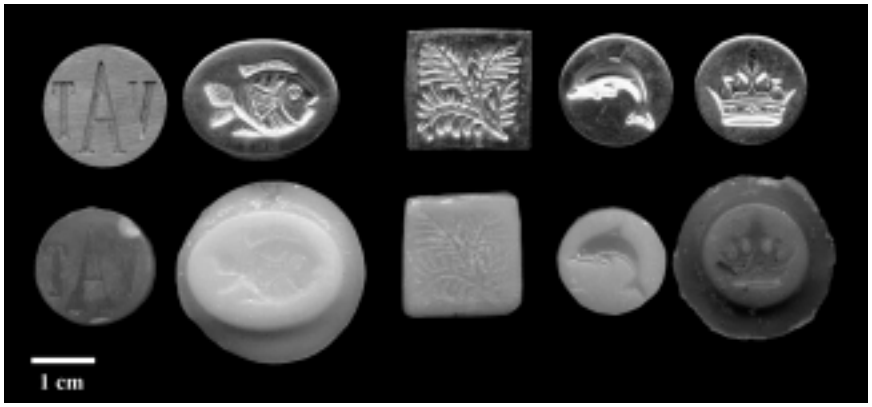

Figure 1 - The original brass stamp seals (top row) along with the beeswax counterfeits (bottom row) created by making a beeswax casting of the clay impression produced by each seal.

Figure 2 - Original and counterfeit seal impressions made in Terra Cotta clay. The original seal impressions (top 2 rows) were made using the fish-design brass seal shown in figure 1. The 2 counterfeits on the bottom row were made using a beeswax casting of its impression in clay.

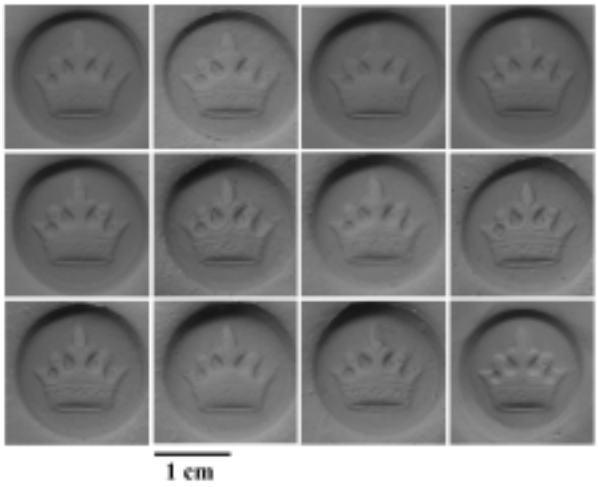

Figure 3 - Which are counterfeits? The seal impression in the lower right hand corner was made using a beeswax casting of a Terra Cotta clay impression. All others were made using the original brass seal.

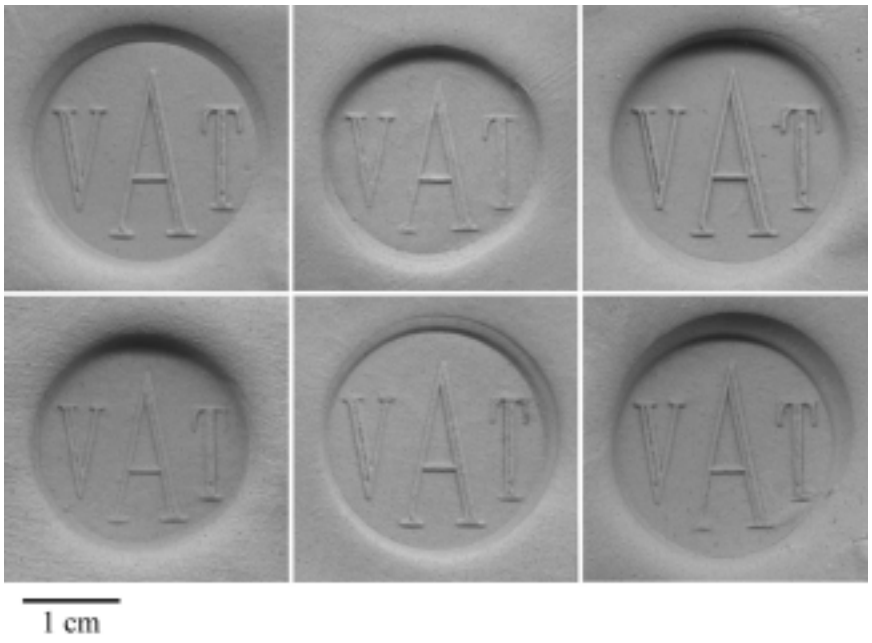

Figure 4 - Original and counterfeit seal impressions in APSW clay. The two counterfeits were made using a beeswax casting. One counterfeit impression is located in the middle of the top row. The other is leftmost in the bottom row.

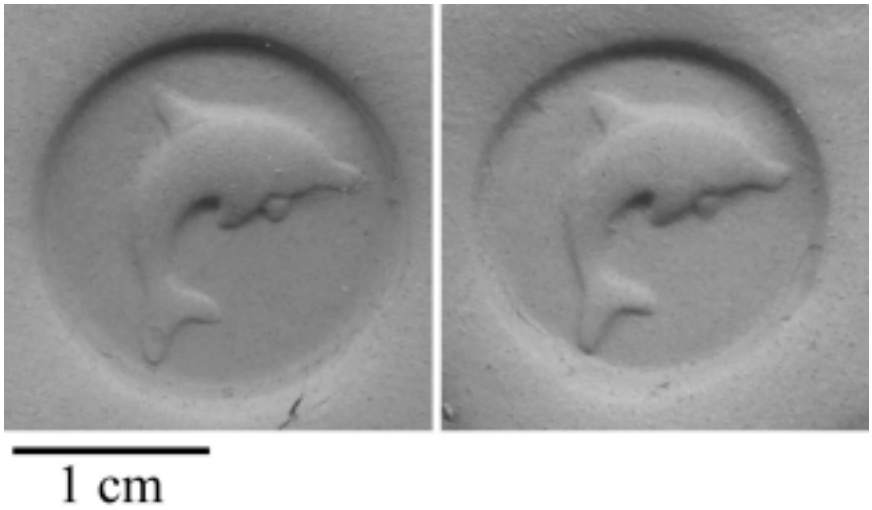

Figure 5 - Original seal impression (left) and counterfeit made from it (right). The casting used to make the counterfeit seal impression was made using APSW clay instead of beeswax. The clay casting was allowed to harden before creating the counterfeit impression in APSW clay shown here.

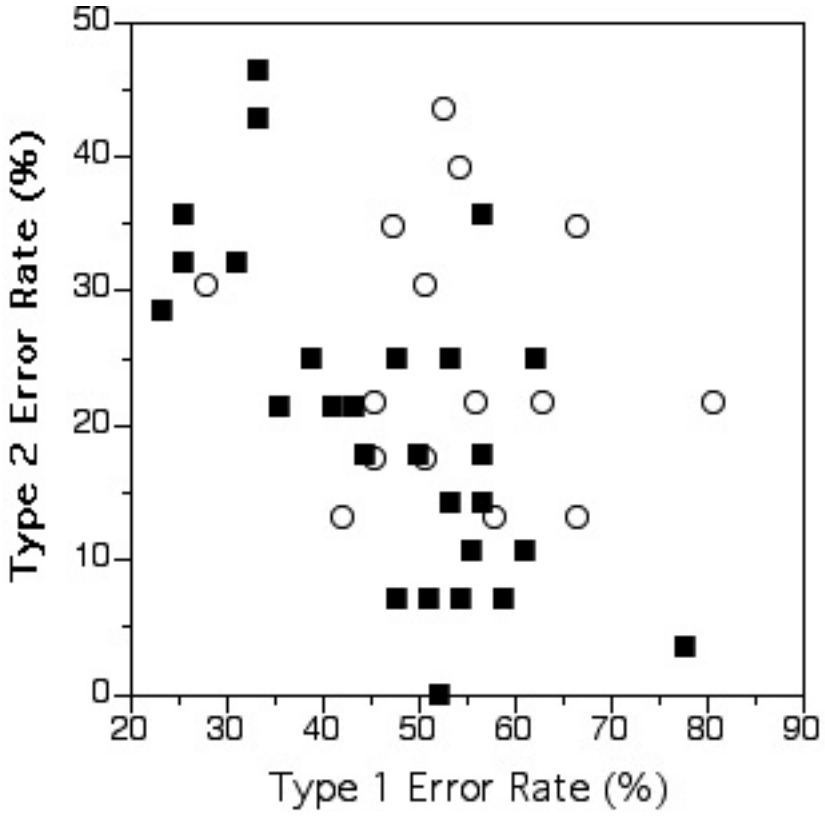

Figure 6 - Type 2 (false accept) error rates vs. Type 1 (false reject) error rates for the counterfeit seal impressions made using the beeswax casting attack (squares) and the clay casting attack (open circles) for each test subject in our survey.

Figure 7 - The top half of the figure is a seal impression made by a cylinder seal (c. 3000 BC) found at Uruk (Iraq) measuring 4.3 cm long by 3.5 cm in diameter. Reproduced from Collon 1987: figure 807. The bottom half of the figure is the seal impression made with the forged cylinder seal carved from wood.

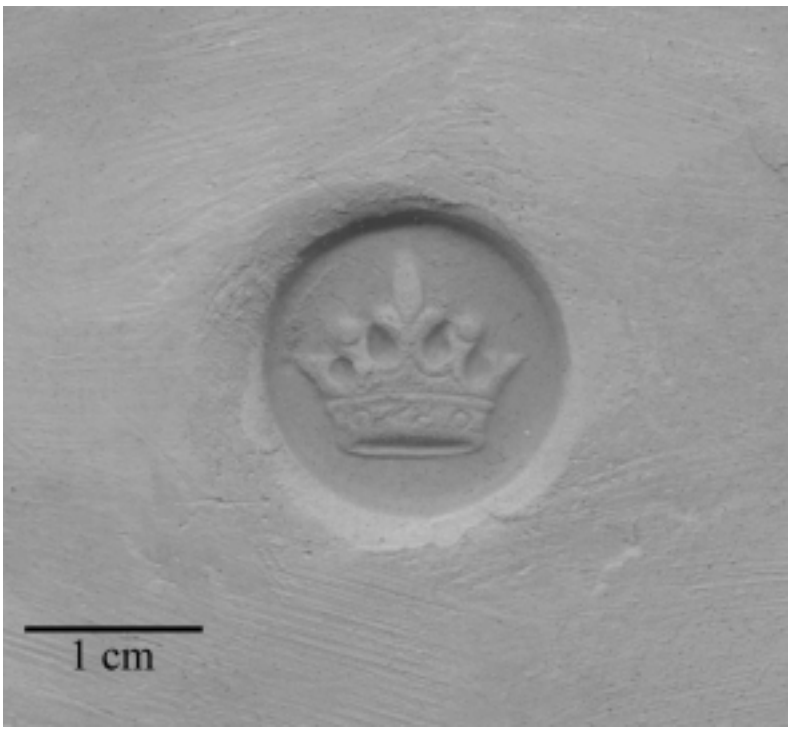

Figure 8 - Clay tablet created by cutting the crown seal impression out of the original (APSW) clay and forming a new clay tablet around it.